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PHANEROZOIC STRATIFORM AND STRATABOUND DEPOSITS OF EGYPT; THEIR STRATIGRAPHIC, PALEO-GEOGRAPHIC, TOPOGRAPHIC AND ENVIRONMENTAL CONTROLS

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ABSTRACT

The present study is concerned with the classification of the Phanerozoic Egyptian mineral deposits of Pb, Zn, Cu, Fe, Mn, Sr, Ba, S, Al, P and the "Egyptian Alabaster". It throws light on the factors, processes and situations (space and time) that controlled the formation and distribution of these deposits in accordance with the geological history of the Phanerozoic Era. The argument(s) about the ore genesis in this work is mainly based on field observations and the degree of congruency and spatial relation between the ores and the host rocks, in addition to the combination and integration of several geological aspects; such as structure, geomorphology, pedology, lithostratigraphy, sedimentology and diagenesis. The ore deposits in question are of stratiform and stratabound types, ranging in age from Early Paleozoic to Plio-Pleistocene. The majority of which, if not almost all, suggest near surface formation under marine, mixed and fresh water conditions; i.e. they do not show evidence whatsoever favouring migration of elements from deep-seated sources. The stratiform deposits show conspicuous sedimentary and diagenetic features and are hosted within certain lithostratigraphic units of shallow nearshore environments, of regional or local magnitudes. The stratabound deposits are intimately related to paleoerosion surfaces (either karstic or non-karstic) and comprise an integral part of the weathering-related profiles. The development of the study ore deposits coincided well with the paleogeographic evolutionalpattern of the Phanerozoic shorelines and the related distributions of paleohighs, as well as paleoclimatic conditions and the sea-level cycles, which prevailed.

INTRODUCTION

The present contribution offers insight into the controlling factors concerning the stratabound and stratifrom Pb, Zn, Cu, Fe, Mn, P, Ba, Sr, S and kaolin deposits and the "Egyptian Alabaster", occurring within the Phanerozoic succession of Egypt (Fig. 1); a further step to demonstrate their geologic settings and modes of formation. The study concentrates on the wide varieties of rock types and environments in which these deposits were accumulated and is based on local as well as regional scale investigations and stratigraphic correlations. Considerable attention is attributed to the main characteristic features of the different ore types, their regional or local paleogeographic concordances with the host rocks as well as the processes involved during their formation. This is accompanied, as mentioned above, with an integration of the several geological aspects that controlled the structural, sedimentological and paleogeographical setti-

ngs of the host rocks and the distribution of paleohighs during the Phanerozoic history of Egypt. The main consequence of this attempt is somehow new and an integral scheme which may explain the situation (space and time) of the ore formation and which may hopefully assist in further exploration for similar sites of ore types.

The different genetic classifications of the Egyptian ore deposits including those occurring within the Phanerozoic strata are recently reviewed and discussed by Hussein and El Sharkawi (1990). Hussein and El Sharkawi (op.cit) presented a modified classification which follows the general scheme outlined by Hilmy and Hussein (1978) and includes review about the geology, origin and economic potentialities of the most important ores. In their classification, the Phanerozoic ore deposits are subdivided into two groups : 1) stratabound ores of sedimentary association (e. g. Zn, Pb, Cu, S and Ba deposits), and 2) ores of sedimentary nature (e.g. Fe, Mn and P deposits; coal, clastic and placers deposits; evaporites and weathering products). Meneisy (1990), in his study on the Phanerozoic volcanic activities of Egypt, related almost all the Phanerozoic Mn, Fe and Cu ores to hydrothermal processes of Tertiary volcanics. Furthermore, he assumed that the metaliferous deposits of the Red Sea are a product of sea-floor spreading and related hot brines.

The formational names used in this work are adopted from the reviewed stratigraphic schemes of Hermina *et al.* (1989) and Said (1990 a & b).

Egypt lies at the northeastern corner of the African plate and consists of the Precambrian basement rocks of the East Saharan Craton and the Arabo-Nubian Shield, above which the Phanerozoic strata were deposited. The basement rocks have undergone various crustal disturbances and deformational events that terminated by the Late-Proterozoic Pan-African tectonothermal episode. The Phanerozoic intraplate deformations and the associated processes of erosion and sedimentation are generally controlled by reactivated basement fault systems and global eustatic changes throughout this Era (Schandelmeir et *al.* 1987; Klitzsch and Wycisk, 1987; Morgan 1990; Meshref 1990 and Said 1990 a & b). Table 1 shows the stratigraphic settings of the study ore deposits and their relation with the main Phanerozoic tectonic events, sedimentary environments, paleoclimates, paleodrainage and volcanic activities as well as the general transgressive or regressive trends of the paleo-shorelines.

PALEOZOIC FRAMEWORK AND RELATED ORE DEPOSITS

At the end of the Pan-African episode, Egypt as a part of Gondwana was at mid-latitudes in the southern hemisphere (Smith, 1981). During the Early Paleozoic, Egypt was rifting towards the south reaching a paleolatitude 70°S during the Ordovician and subsequently moved northwards rotating 180°. The paleogeographic distribution of much of the Paleozoic sediments of Egypt was controlled by a NNW striking structural relief of Early Paleozoic, when a large NNW oriented depocenters and uplifts were established (Fig. 2A). During the Early Cambrian, Sinai and the northern Egypt were transgressed by a shallow sea (Fig. 2B) followed by rapid fluvial progradation. Silurian and Devonian seas have advanced only into the western border of Egypt (Fig. 2 B,C). During the Early Carboniferous, the northwestern corner of Egypt was transgressed by a shallow sea, while the southeastern sectorremained positive land under erosion (Fig. 2C). Two types of ore are recorded in the Cambrian and Carboniferous rocks of the Um Bogma environ, Sinai: 1) Cambrian stratiform malachite related to the Cambrian transgressive episode, and 2) Carboniferous stratabound (Karst-hosted) Mn deposit related to intra-Carboniferous paleokarst event.

As a consequence of plate collision and

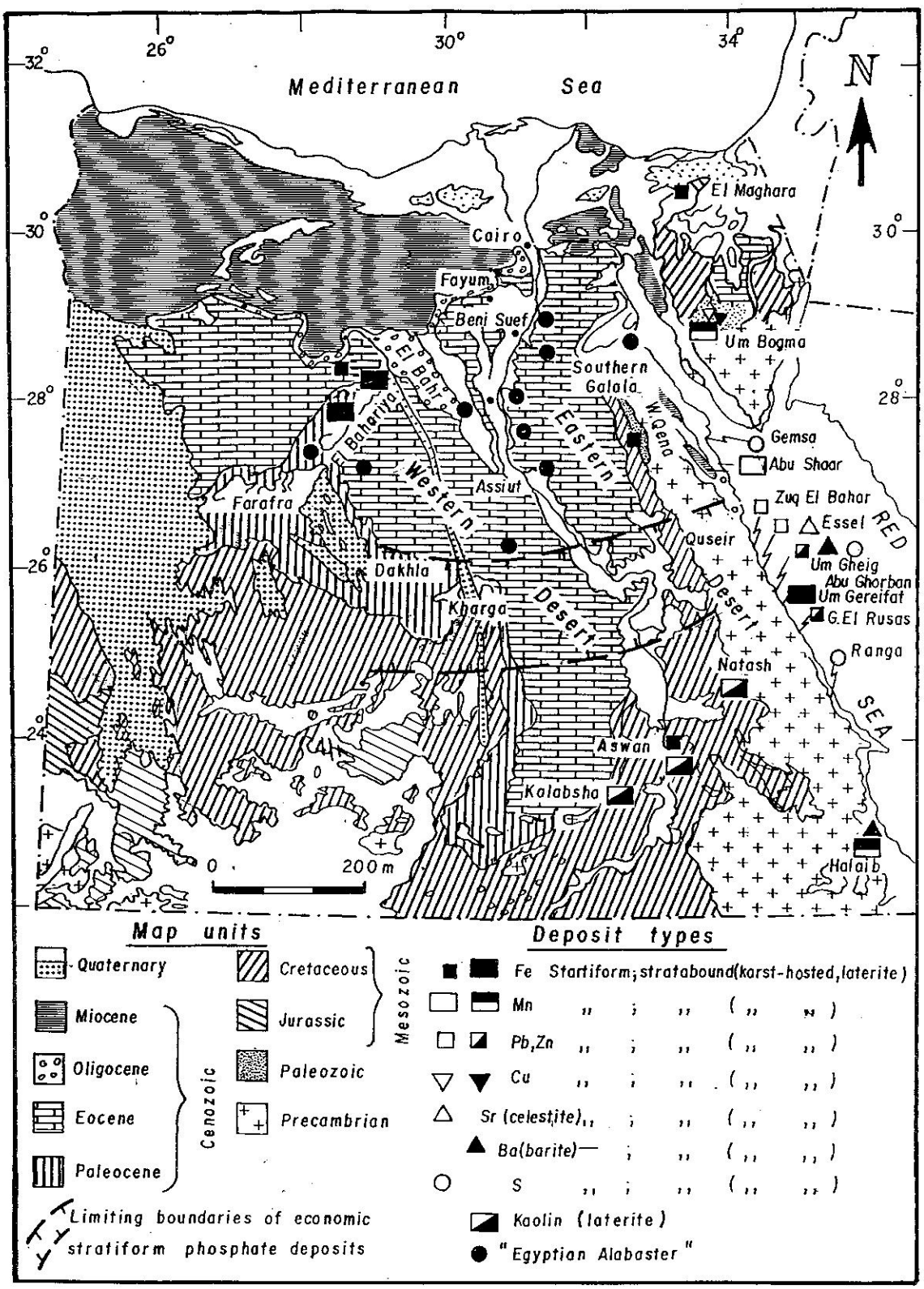


Fig.(1) Simplified geological map of Egypt, and distribution of the study deposits (based on the geological map of Egypt, scale 1:200,000, EGSMA, 1981)

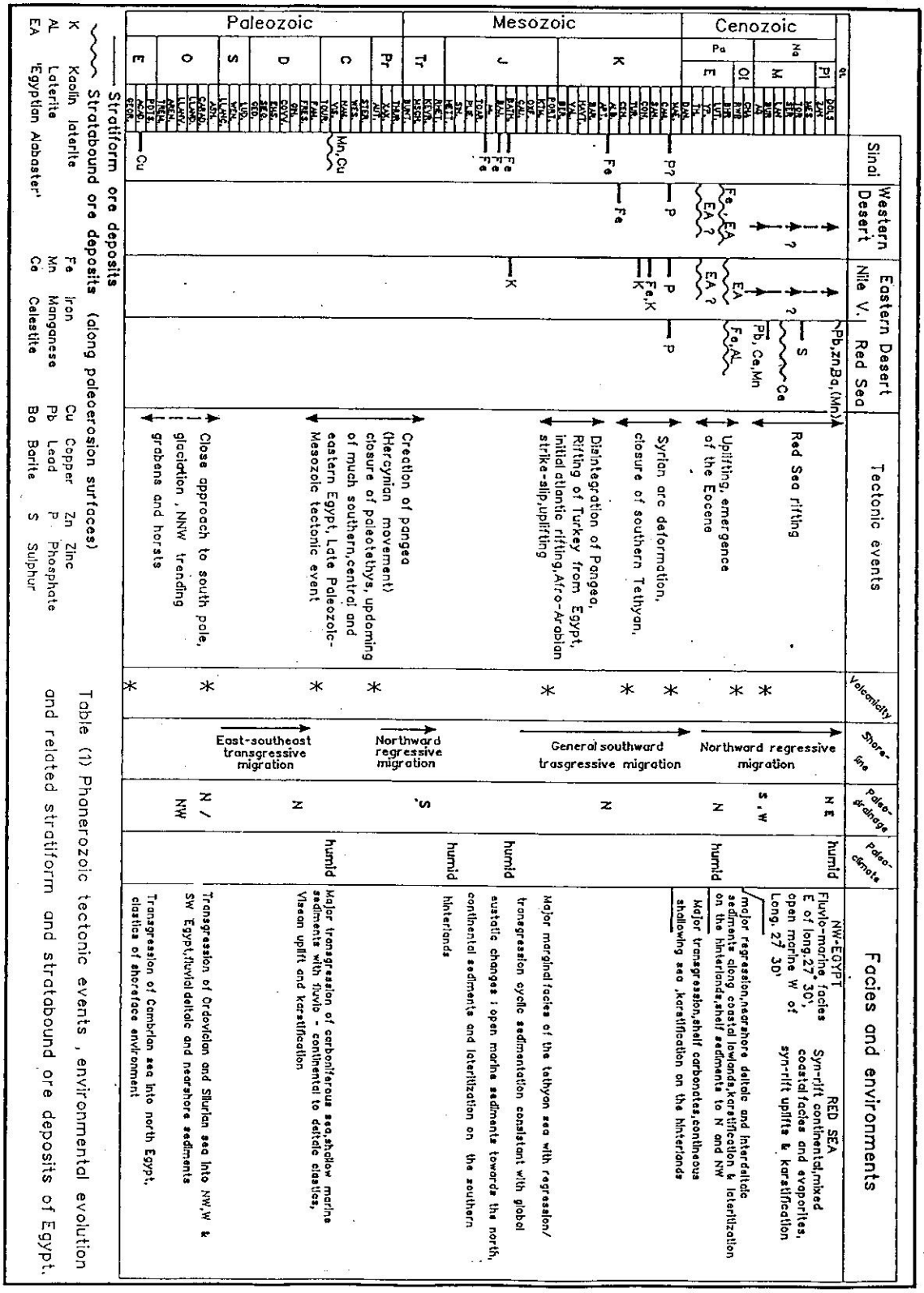
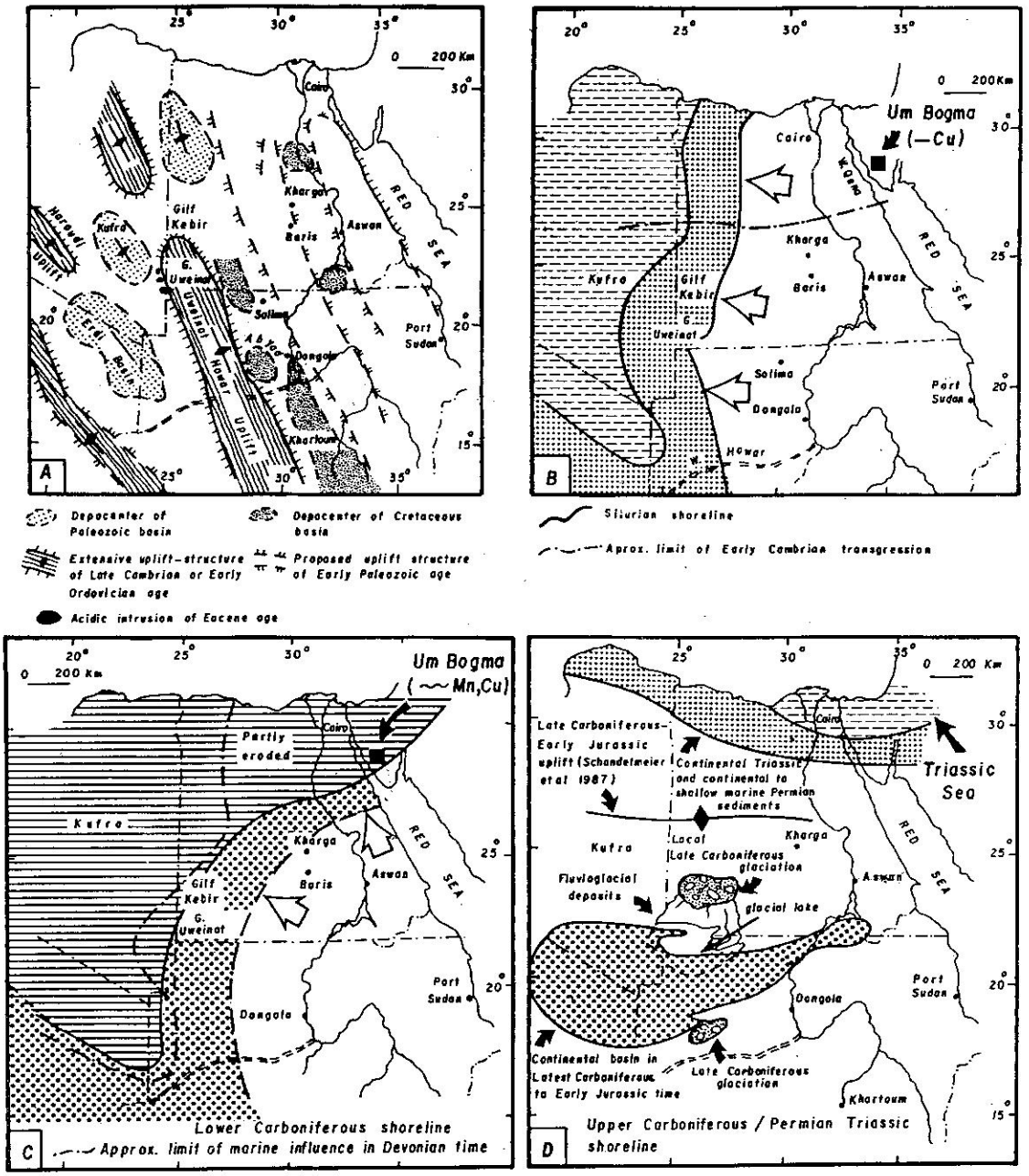


Table (1) Phanerozoic tectonic events, environmental evolution and related stratiform and stratabound ore deposits of Egypt.

Phanerozoic Stratiform and Stratabound Deposits



1 = Positive areas ; 2 = Open marine ; 3 = Transitional coastal to fluvial environment ; 4 = Open to shallow marine with deltaic fluvial intercalations ; 5 = Alluvial deposits ; 6 = Stratiform malachite ; 7 = Stratabound (Karst – hosted) Mn deposit ; 8 = Possible paleocurrent direction

Fig. (2 A) Early Paleozoic structural relief and its possible later reactivation (after Schandelmeier et al. 1987)

Figs. (2B-D) Paleogeography of the Paleozoic systems (after Klitzsch and Wycisk, 1987) and distribution of the related stratiform and stratabound deposits.

construction of the supercontinent Pangea (Late Paleozoic - Early Mesozoic tectonic event, Klitzsch, 1986 or "Hercynian" event, Meshref, 1990), Upper Egypt was uplifted along rejuvenated ENE trending faults (Schandelmeir *et al.* 1987) and volcanic activities predominated (Meneisy, 1990). Related basaltic eruptions cut across the Paleozoic strata and the enclosed Mn and Cu deposits of the Um Bogma environ.

Cambrian Paleo-shoreline and Related Stratiform Malachite, Um Bogma, Sinai

Surface exposure of the Cambrian strata are identified in Sinai (Um Bogma and Gabal Araba areas, Weissbrod, 1969; Seilacher, 1990, etc) and in the Eastern Desert at northern Wadi Qena (Seilacher, 1990; Abdallah *et al.* 1992 and others). They comprise the shore-face clastic sediments of the Araba Formation with its trilobites and bilobites tracks and the overl ying fluvial to deltaic sediments of the Naqus Formation. Stratiform malachite is found within the upper part of the shoreface clastics of the Araba Formation in Um Bogma environ (Fig. 3), which are correlated with the Cambrian cupriferous sediments of Timna, Israel and Wadi Dana, Jordan.

The malachite of this type occurs as interstitial material in the host sandstone, siltstone and shale interbeds and is often associated with kaolinite, illite, chlorite and calcite. Its megascopic and microscopic geometric patterns are almost conformable with the syn-sedimentary structures of the host rocks, e.g. horizontal-, -undulatory - and cross laminations, ripple marks, flasers, biogenic, scour and fill structures and desiccation cracks (El Sharkawi et *al.* 1990a). This high degree of congruency together with the paleotopographic position and environment of the host sediments suggest that Cu has been leached from nearby copper-bearing basement paleohighs and transported into the basin of deposition as bicarbonate or mobile complexes, where it was diagenetically crystallized into malachite during the drying-out of the host sediments. The occurrence of this malachite type in the Um Bogma environ may be attributed to the availability and proximity of copper-bearing Precambrian hinterland.

Lower Carboniferous Stratabound (Karst-Hosted) Mn Deposit, Um Bogma, Sinai

The lowermost early Carboniferous sediments are represented by the carbonates of the Um Bogma Formation (Tournasian - Visean). This formation, 0-43 m thick, is of limited distribution and restricted to the Um Bogma environ. It rests directly above the Precambrian basement in the northeastern part of the Um Bogma environ, where it attains its maximum thickness. East and southeastwards, the rocks of this formation are highly attenuated and truncate different stratigraphic horizons of the Lower Paleozoic Araba and Naqus formations. The deposition of the Um Bogma carbonates was interrupted by syndenosctional uplifting event accompanied With subaerial karstificcation and development of deep weathering (karst) profile hosting Mn ore (Fig. 3), (El Sharkawi *et al.* 1990b). The upper part of the Um Bogma Formation is formed of transgressive rhythmic alternations of dolostones and mudstones resting unconformably on the underlying karstified rocks and the associated Mn ore (Fig. 3). Rapid fluvial progradation and near - shore sedimentation followed the deposition of the upper Um Bogma caubonates and resulted in the accumulation of the fluviatile to coal - bearing swampy sediments of the Abu Thora Formation (Fig. 3).

South the Um Bogma environ, at Wadi Feiran, Wadi Mokattab and Gabal Abu Durba, the Um Bogma Formation is completely missing,, the overlying Abu Thora clastics rest directly on the Cambrian Naqus Formation and are overlain by the Upper Carboniferous shales and siltstones of the Durba Fomation (Klizsch, 1990,El Barkooky, 1992). At northen Wadi Qena, Eastern Desert, the Abu Thora Formation also rests directly above the Cambrian

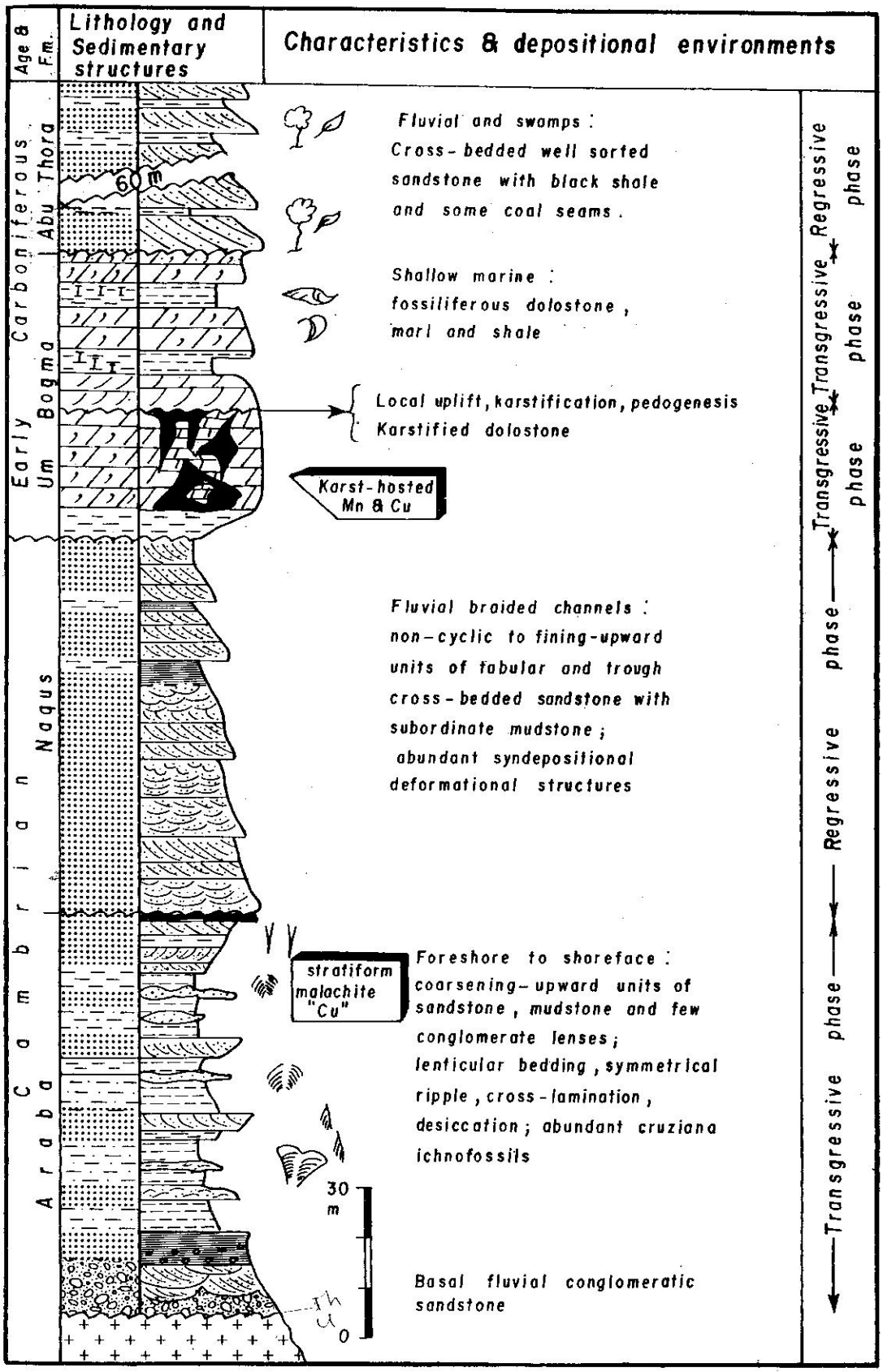


Fig.(3) Stratigraphic column of the Paleozoic rocks of Baba mine, Um Bogma region.

rocks. Along the western side of the Gulf of Suez, at Wadi Araba, Bir Abu Darag and Northern Galala, only the Upper Carboniferous to Permian, shallow marine and continental successions of the Rod El Hamal, Abu Darag and Aheimer formations (Abdallah and Adindani,1963, abdallah, 1992) are exposed. The Um Bogma carbonatis are absent. At the southwetern corner of the Western Desert (Abu Ras plateau at Gbal Uweinat - Gilf El Kebir landstretch), the Lower Carboniferous Wadi Malik Formation consists of fluviatile to shallow marine clastics followed by the Upper Carboniferous fluvio - glacial sediments of the North Wadi Malik Formation (Klitzsch and Wycisk, 1987).

This overall view concerning the Carboniferous rock units, their distribution, facies and unconformities and the setting of the karst-hosted Mn ore reflect the predominance of tectonic instability accompanied with block faulting during their formation. This can also explain the limited distribution of the lowermost Um Bogma carbonates and the intra-Um Bogma paleokarst in the Um Bogma environ and the absence of similar rocks in the surrounding regions.

The intra-Um Bogma paleokarst profile (Fig. 3) comprises three transitional horizons: an upper topsoil horizon, a middle subsoil horizon and a lower highly karstified manganiferous carbonates (El Sharkawi *et al.* 1990b). The topsoil horizon, 20-60 cm thick, is a leaching horizon being composed of residual kaolinite, gibbsite and jarosite mixed with red and yellow ochres (pisolitic and manganiferous in part), alunite nodules, bituminous plant remains and land-derived palynomorphs. Barite and gypsum veinlets and rosette forms are also present . Mn, Cu and U bearing carbonate, chloride, sulphate, silicate, phosphate and vanadate minerals (El Sharkawi *et al.* 1990a; Hussein *et al.* 1992) are frequently distributed within the topsoil products, filling shrinkage cracks or may migrate downward through solution fractures into the subsoil Mn-rich horizon. The formation of such minerals together with the alunite, barite and gypsum demarcates the general desiccation of the soil products during the end of the paleoerosion (paleokarst) cycle. Redeposited crustified Mn oxides and hydroxides (romanechite, pyrolusite, manganite, hausmanite) with or without goethite and hematite are the main components of the subsoil horizon, filling solution cavities and channels and cement collapse breccias. The karstified country rocks show varieties of vadose and vadose to phreatic solution features and wall rock alteration processes which correspond to those characterizing the telegenetic zone of the ideal karst profile of (Choquette and Pray, 1970). They include dissolution, collapsing, pulverization and accumulation of earthy Mn and Fe products, formation of coarse-grained Mn and Fe-rich dolomite and ferroan calcite, dedolomitization, speleothem formation, orthosparite cementation and vadose geopetal fillings. El Sharkawi *et al.* (1990 a&b) discussed in detail the pedogenesis and the related microbiological processes and physico-chemical conditions that prevailed during the active periods of weathering and the concentration of the Mn ore in the subsoil horizon.

MESOZOIC FRAMEWORK AND RELATED ORE DEPOSITS

Triassic transgression followed the Late Paleozoic ("Hercynian") tectonic event and affected only the structurally low areas of northeastern Egypt (Fig. 2D), where the marine Arif El Naqa Formation was laid down. Southwards, along the Gulf of Suez, the upper part of the Permo-Triassic Qiseib paracontinental sediments (Abdallah and Adindani, 1963; Barakat *et al.* 1986) were accumulated.

During Jurassic-Early Tertiary, two main tectonic events related to Tethyan plate tectonics and accompanied with uplifts and volcanic activities took plsce. These are: Late Jurassic - Early Cretaceous tectonic phase which was con-

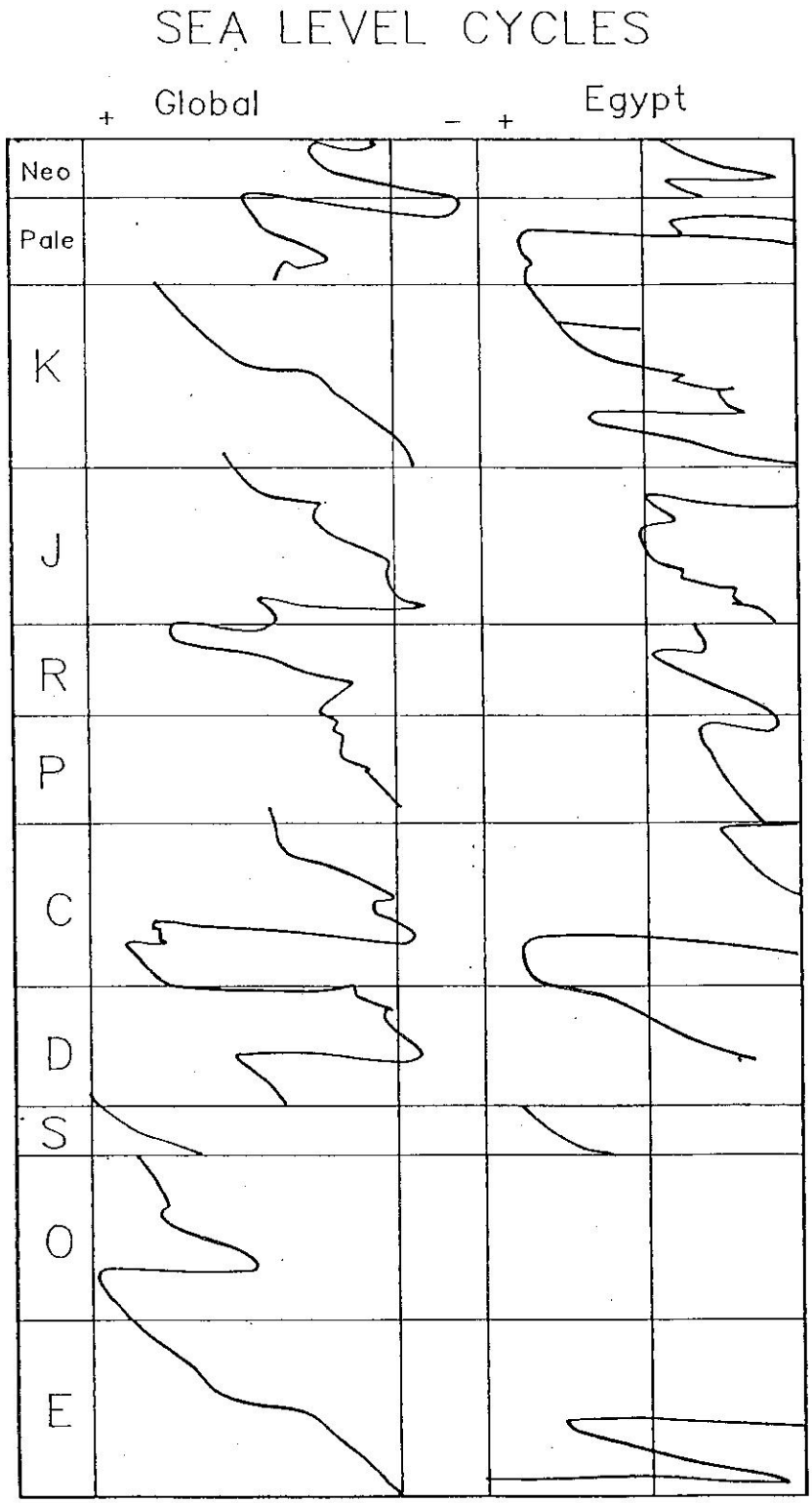
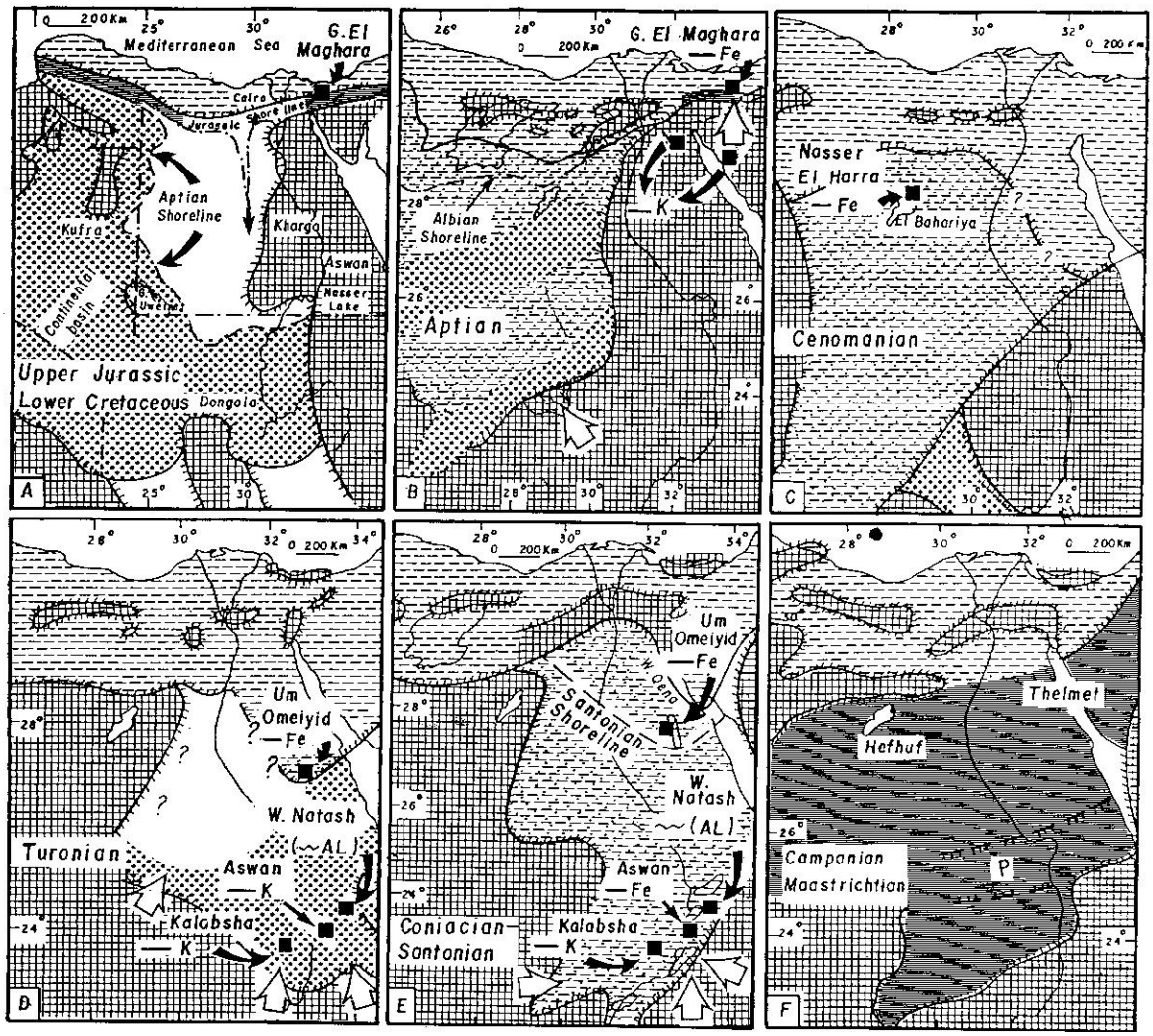


Fig.(4)Comparison of global & Egyptian Phanerozoic eustatic sea-level cycles (Morgan , 1990)



1 2 3 4 5 —Fe 6 —K 7 ~AL 8 P 9 10

1 = Positive areas; 2 = Open marine sediments; 3 = Nearshore mixed environments; 4 = Fluviomarine sediments; 5 = Fluviatial sediments; 6 = Stratiform ironstone; 7 = Kaolin laterite; 8 = Bauxitic laterite; 9 = Limiting boundaries of economic phosphate deposits; 10 = Possible paleocurrent direction

Fig. (5) Paleogeography of the Mesozoic series and stages (Fig. 5A after Klitzsch and Wycisk 1987 Figs. 5 B-F after Said 1990a) and distribution of the related stratiform and stratabound deposits.

temporaneous with the disintegration of Pangea and the associated initial rifting of Aglantic drifting of Turkey from Egypt, cgosing of the paleotethys, opening up of the Alpine TETJUS (NEOTETHYS) and Afro - Arabian strikee - slip faulting (Smith, 1981), and 2) Late - Cretaceous - Early Tertiary tectonic phase ("Laramide" or Syrian arc system, Said, 1962) which was roughly contemporaneous with the stages of oceanic closure in the southern Tethys and collision of Laurasia and Afro - Arabian plates (Smith, 1981).Since the paleolatigude of Egypt was along or just north of the equtor, warm and humid to subhumid paleoclimatic conditions predomimated. Coastal plains and shallow shelfs, of low relief were costructedin the northern and central parts of Egypt, separating erosive paleohigs and continental sediments towards the south from the marine Tethyan sea to the north. A major alternating transgressive, migration of the Tethyan shorelines prevailed. Paleodrainage and regressive phases accompanying a general southward transgressive was towards the north (Klitzsch, 1984). These Ttansgressive - regressivee phases were basically cinsistent with global eustatic cycles (Fig. 4), but with some modifications related to regional or local tecctoic movements and creation of depocenters and strctural highs (Morgan, 1990: Said, 1990).

Stratiform oolitic and non - oolitic ironstones with equivalent laterites (in situ or transported) are mostly congruent with the paralic facies of the Jurassic to Santonian Tethyan paleo - shorelines and the associated lateritization and continental sedimentation on the adjacent hinterlands. During the Campanian - Maastrichtian time, stratiform phosphorite deposits were accumulated, also in a relatively stable epicontinental marginal facies of the Tethys.

Jurassic-Lower Cretaceous Paleo-Shorelines and Related Ironstones and Laterites

The Jurassic sea covered northern Egypt (Fig. 5A). The thickest Jurassic sequence crops out in northern Sinai at Gabal El Maghara and comprises an alternation of transgressive marine and regressive paralic units (Fig. 5). The paralic facies associations include coal seams and ironstone bands. Albian-Aptian ? shallow marine carbonates including ironstone bands are also exposed in Gabal Manzur, east of Gabal El Maghara (Fig. 6). During the Jurassic-Lower Cretaceous transgressive - regressive cycles on northern Sinai, the southern hinterlands were under intensive erosion and deposition of the continental clastics and the associated currently quarried kaolin-rich laterites and paleosols of the Raqaba, Temmariya and Malha formations in the southern Sinai and the Gulf of Suez (Fig. 5B) and the equivalent continental clastics of the Gilf Kebir, Six Hill and Sabaya formations in the southern Western Desert.

The Jurassic and Lower Cretaceous ironstones of northern Sinai are of variable thicknesses, ranging from few centimeters to 1.53 m with 17 to 42% Fe. They are generally compact, tabular, lenticular and in certain places they are in the form of large to medium scale troughs. The ironstone bands comprise two, rather distinct facies types: a) Non-oolitic ironstone horizons including concretionary, massive, clayey ochreous and rhythmic laminated varieties. They may represent paleosol or ferruginous mud-flat interval interrupting the cyclic clastic sequences of the host Jurassic deltaic sediments (Fig. 6). Root moulds, flaser, cross and wavy-laminations, ripple marks, bioturbations, scour and fill structure and desiccations are frequently observed in these horizons, and b) Oolitic ironstone bands with goethite and chamosite ooids in chamosite and micrite matrix, often encountered within the lagoonal, mixed intertidal to shoal facies associations of the Lower Cretaceous succession (Fig. 6). The main diagenetic processes observed in these ironstone types are: a) compaction and cementations, b) formation of mouldic cavities, c) pyritiza-

tion and formation of biogenic pyrite framboids, d) sideritization of grains, matrix and cement, e) authigenic quartz overgrowths, f) oxidation of pyrite, siderite and chamosite, g) replacement of siderite and chamosite by calcite, h) dolomitization, and i) pore fillings. These processes are controlled by near-surface conditions (oxidation-reduction) and the energy of the basin (El Sharkawi *et al.* 1989).

Upper Cretaceous Paleo-Shorelines and Related Ironstones, Laterites and Phosphorites

Cenomanian Ironstone

Cenomanian transgression covered most of the northern and central Egypt (Fig. 5C) depositing marine carbonates, marls and shales towards the north (Halal, Raha and Galala formations) and the equivalent paralic and shallow marine sediments of the Bahariya and El Heiz formations in the central Western Desert. Further south, the comparable clastics of the Maghrabi Formation (Kharga - Dakhla district) show lesser marine influence and include abundant vertebrate and plant remains. The paralic Bahariya Formation (Fig. 6) includes within its lower and upper members ironstone bands and lenses, 15-150 cm thick, well exposed in El Bahariya depression or along its surrounding scarps as a result of repeated tectonic pulses of the Upper Cretaceous - Lower Tertiary "Laramide" tectonic event. Economic Cenomanian ironstone bands are represented in El Harra and Nasser mine areas; their mineralogy and sedimentological characteristics are now under detail investigation. Estuarine Cenomanian clastics of the Bahariya Formation including ironstone bands, each of up to 1 m thick, are recently recorded to the west of Lake Nasser at Gabal El Saad (Issawi and Osman, 1993).

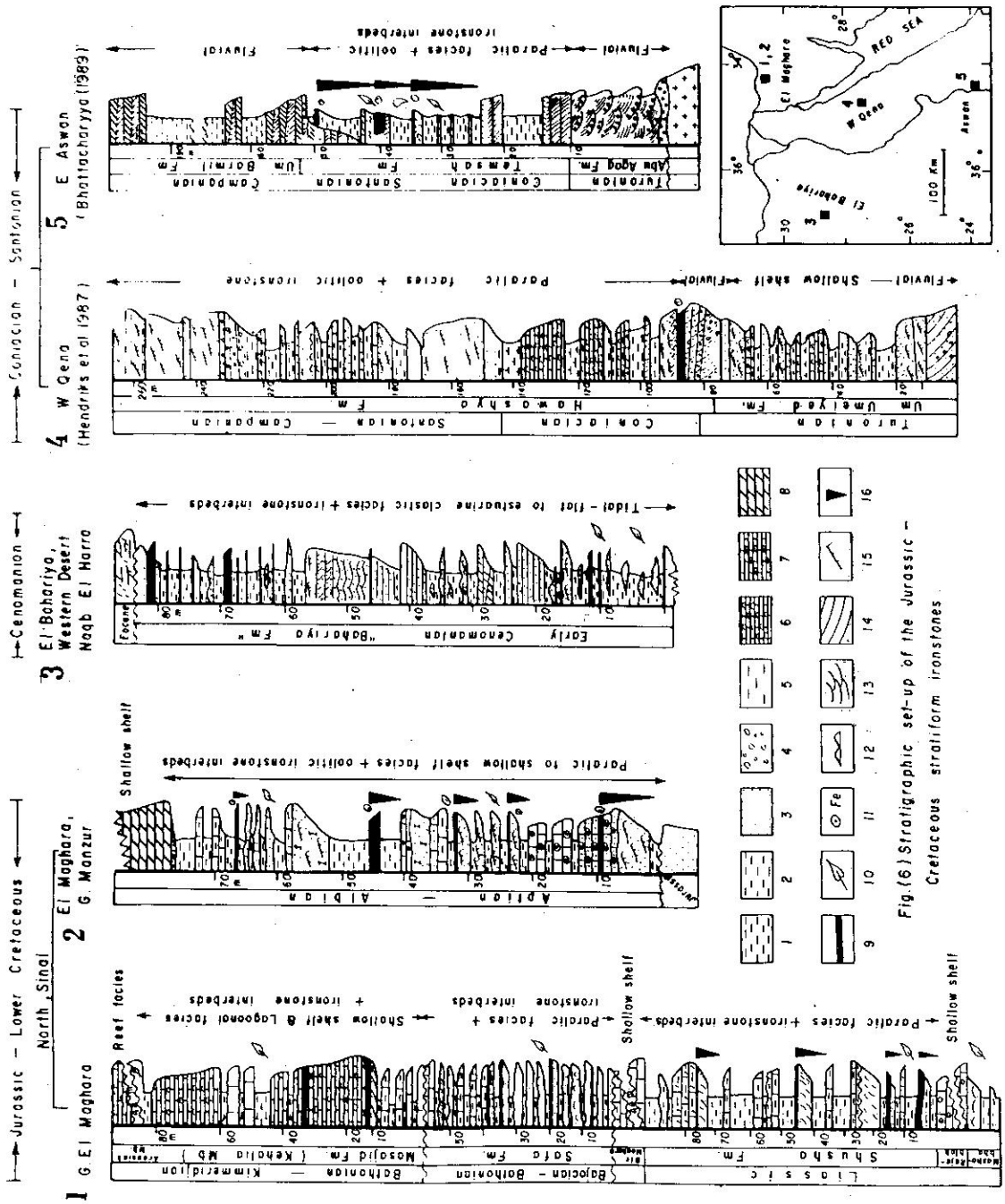
Turonian Laterites

A major regressive phase has been established during the Middle Turonian, accompanying an important pulse of the "Laramide" movement which elevated southern Egypt, El Bahariya arc and numerous structures across northern Egypt and Sinai (Fig. 5D). Thick marine carbonates related to the Wata Formation were deposited over the structural lows of northern Egypt, while the coeval paralic sediments of the Um Umeiyed Formation were deposited southwards and crop out in central Wadi Qena (Fig. 6). Meanwhile, the extreme southern hinterlands were subjected to deep weathering processes inducing lateritization and bauxitization and recieved simultaneous fluvial sedimentation constituting the lower part of the Taref Formation of north Kharga and the Abu Agag Formation of northeast Aswan.

Exposed outcrops of lateritized Precambrian basement rocks are widespread east and south of Aswan and in the western part of Kalabsha area near Sinn El Kadabb (Fig. 5D). The Abu Agag Formation attains 5 - 40 m thick at its type locality, Wadi Abu Agag, where it overlies an irregular relief of extensively lateritized Precambrian rocks. It consists of fining upward sequences of braided river environment, including trough cross - bedded conglomerates and sandstones, kaolin-rich laterite and *in situ* paleosols. Southwest Aswan at Wadi Kalabsha, the probably concommitant 9 m kaolin Member of Said and Mansour (1971) is overlain and undelain by fluvial conglomeratic sandstones similar in composition and textures to those of the Abu Agag Formation. Eastward of Aswan at Wadi Natash (Fig. 5D), the upper part of the Abu Agag Formation interfingers with the Natash volcanic sheets and their lateritic caps.

The Turonian laterite deposits can be classified into two types according to their relation with the country rocks within which they are found; these are:

a) Stratabound authochthonous bauxitic laterites (fossil latosols) of two different stratigraphic positions including: latosol capping Precambrian granites, schists and migmatites and is truncated by the Abu Agag clastics; and latosol capping Creta-


Jurassic – Lower Cretaceous
Coniacian – Santonian
Cenomanian
North Sinai
1 G. El Maghara
2 El Maghara, G. Manzur
3 El-Bahariya, Western Desert Naqb El Harra
4 W Qena (Hendriks et al 1987)
5 E Aswan (Bhattacharyya (1983))
Shallow shelf
Reef facies
Fluvial
Paralic facies + oolitic ironstone interbeds
Shallow shelf & Lagoonal facies + ironstone interbeds
Paralic facies + ironstone interbeds
Shallow shelf
Tidal – flat to estuarine clastic facies + ironstone interbeds
Paralic to shallow shelf facies + oolitic ironstone interbeds
Fluvial — Shallow shelf — Fluvial
Paralic facies + oolitic ironstone
Fluvial — Paralic facies + oolitic ironstone interbeds — Fluvial
Jurassic
Bajocian – Bathonian
Bathonian — Kimmeridgian
Safa Fm.
Mosozid Fm. (Kehdid M5)
Shusha Fm
Aptian — Albian
Early Cenomanian "Bahariya Fm"
Turonian
Coniacian
Santonian — Campanian
Cretaceous
Tertiary
Um Uomeiyed Fm.
Hawashyd Fm
Abu Aqaq Fm.
Tamsah Fm
Um Bormil Fm
RED SEA
El Maghara
W Qena
Aswan
El Bahariya
100 Km
Fig.(6) Stratigraphic set-up of the Jurassic – Cretaceous stratiform ironstones

ceous volcanic rocks and is truncated by the upper clastics of the Abu Agag Formation. The *in situ* latosol profiles comprise an upper iron-rich pisolitic duricrust, 20-50 cm thick, with or without silcrete interlayers; a middle bleaching (mottled) horizon, 2-10 m thick, rich in hydromica and nodular kaolinite; and a lower argillaceous lithomarge (saprolite) horizon, 5-20 m thick consisting of kaolinitized rock fragments and mineral grains in kaolinite-rich matrix, grading downward into weathered parent rocks. Gibbsite, boehmite, maghemite and montmorillonite are also recorded in these latosol profiles (Said *et al.* 1976).

b) Stratiform allochthonous kaolin-rich laterites, locally bauxitic, intercalated within the Abu Agag fining-upward sequences. Irregular shaped kaolinitized basement fragments and kaolinite and goethite pisoliths accumulated within the internal troughs of the cross-bedded sandstone bodies. Kaolinitic mudstones, pisolitic in part, also form thin layers terminating the fining - upward sequences of the host rocks. *In situ* secondary bauxitization of some of the kaolinitic mudstone intervals resulted into the development of bauxite-bearing latosol profiles (Germann *et al.* 1987).

Coniacian-Santonian Ironstones

The paleogeographic patterns of the Coniacian - Santonian shorelines were obviously controlled by two main factors: a) continuation of the Late Cretaceous - Early Tertiary "Laramide" tectonic movement, and b) southward transgression of shallow Coniacian - Santonian sea through a restricted NS trending intracratonic embayment which extended until northern Sudan (Fig. 5E). Genuine marine sediments were deposited in the structural lows of northern Egypt and the Gulf of Suez area: (i.e. Abu Rawash B and C of the Abu Rawash Formation and the correlatable Matulla Formation, respectively). Meanwhile, nearshore paralic sediments including stratiform ironstone bands dominated within the restricted Coniacian-Santonian basin. Such paralic sequences crop out at central Wadi Qena (Hawashiya Formation) and at the vicinity of Aswan (Timsah Formation), (Figs. 5 E, 6). At central Wadi Qena, the paralic Haawashiya Formation is followed conformably by the Campanian marine Rakhiyat Formation; while, the Timsah Formation of Aswan is overlain by the Santonian - Lower Campanian fluvial sediments of the Um Barmil Formation. These stratigraphic settings may indicate sea regression from Aswan area during the Santonian - Campanian time in response to synsedimentary uplifting of this area.

The ironstone bands of Aswan were mined until recently and investigated by many authors (e.g. Attia 1955; Germann *et al.* 1987; Bhatacharyya, 1989). The host Timsah Formation (Fig. 6) starts with an alternation of highly bioturbated sandstones, kaolinitic mudstones and shales; rich in *Skoliths* and marine fauna as well as flora of humid climate (Germann *et al.* 1987). These are followed by shoaling upward sequences of prograding delta consisting of kaolinitic mudstone, fine-grained sandstone and oolitic ironstone. The oolitic ironstone bands (20 cm - 1.2 m thick) are highly bioturbated and show even - and cross lamination and graded - bedding. They consist of hematite, goethite, chamosite, Fe-chloride, siderite, kaolinite, organic and phosphatic remains, quartz grains and ferruginous peloids and ooids. Sufficient input of fresh water carrying iron and some kaolinitic clays and gradual starvation of the basin are concluded to be the main factors that should be taken into consideration when interpreting the formation of these ironstone bands (Bhattacharyya, 1989).

The lateral facies and thickness variations of the Timsah Formation and the associated ironstone bands and their genesis are currently under detail investigation by the IEP (Iron Exploration Project) team of the Cairo University and the Geological Survey of Egypt.

Campanian - Maastrichtian Stratiform Phosphorite Deposit

Economic phosphate strata are confined to the Upper Cretaceous shoreline successions of the Quseir variegated shales or Mut Formation (Campanian) and the Duwi Formation (Campanian - Maastrichtian). These two units comprise the phosphorite Duwi Group of Glenn and Arthur (1990) and are best exposed in a generally E-W trending belt extending along the middle latitude of Egypt (Fig. 5F). The Duwi Group strata (up to 145 m thick) consist of a relatively sediment-starved heterogeneous mixture that were deposited in a generally shallow epicontinental seas, resulted during Campanian - Maastrichtian transgressive event, extended across the northern margin of the Arabo-Nubian Craton and deepened towards the north. Northwards, chalky limestones of open marine condition (the lower part of the Sudr Formation, Sinai and the Khoman B in the Western Desert) were accumulated. Within the Duwi Group, two main depositional realms are identified by Glenn and Arthur (1990): a) a shallow hemipelagic environment accompanying initial stages of marine transgression and conductive to the formation of organic-rich shales, biosiliceous sediments and phosphorites, and b) a relatively high energy depositional regime accompanying sea-level drop during which deltas advanced. Glauconite were reworked seawards and prograding oyster banks became periodically exposed to episodes of fresh water diagenesis. Lenticular and massive phosphorites are viewed as the result of current winnowing and concentration of authigenic grains initially precipitated in reducing environment associated with shales and biosiliceous sediments.

CENOZOIC FRAMEWORK AND RELATED ORE DEPOSITS

The Cenozoic evolution in Egypt was governed by global eustatic sea-level changes and crustal deformations involving the culmination of the "Syrian arc" or "Laramide" movement (Early Tertiary), Oligo-Miocene volcanic activity and the initiation and formation of the Red Sea rift system. Humid and warm condition dominated most of the Tertiary, while arid episodes were of short durations. A relatively long interval of aridity was exclusively a Late Pleistocene feature (McCauley *et al.* 1982; Said, 1990a). A worldwide elevation of sea level during Late Cretaceous - Early Tertiary led to the submergence of most Egypt by Tethyan epicontinental seas, depositing the Dakhla shales, chalk formations and Esna shales. This transgressive phase culminated in lower Eocene, leading to carbonate deposition of the Thebes Formation (Fig. 7A). Since Upper Lower Eocene time, a major regressive phase started; the Middle Eocene shoreline was approximately along the south Minia - El Bahariya latitudes (Fig. 7A). The Early Cenozoic consequent streams (Gilf system of Issawi and McCauley, 1992) followed this phase of sea retreat and resulted in the initial stripping of the emerged lower Tertiary, Mesozoic and Paleozoic sediments to the south. The denudation of these rocks was accelerated by surface and subsurface karst processes (Issawi and McCauley, 1992). A main break of sedimentation during the Middle Eocene was detected in the stratigraphic records of the Eastern and Western Desert (Said, 1990b). In El Bahariya region (Western Desert), this stratigraphic gap is manifested by paleokarst features and development of the associated lateritic iron ore.

During the Upper Middle and Late Eocene times, further northward retreat of the shoreline took place. A Late Eocene delta was developed in the Fayum basin, where the deltaic sediments of Qasr El Sagha Formation were laid down (Fig. 7B). The Oligocene shoreline was confined to the north of that of the Upper Eocene (Fig. 7C) and consequently fluvial sediments (Gabal Ahmer and Qatrani formations) were deposited in the Suez-Cairo-north Fayum stretch and El Bahr area (El Bahariya re-

gion), while shelf marine sediments (Dabaa Formation) dominated to the north (north Western Desert). South of the Upper Eocene and Oligocene shorelines, paleokarstification involving lateritization took place (El Aref *et al.* 1987, 1991; Philip *et al.* 1991).

During the Neogene, two main depositional regimes were developed: a) continental and shallow marine environments accompanying an advanced northward sea retreats and covering the extreme northern part of Egypt (Figs. 7D,E), and b) rift-related continental and coastal environments corresponding to the Red Sea rift dynamic.

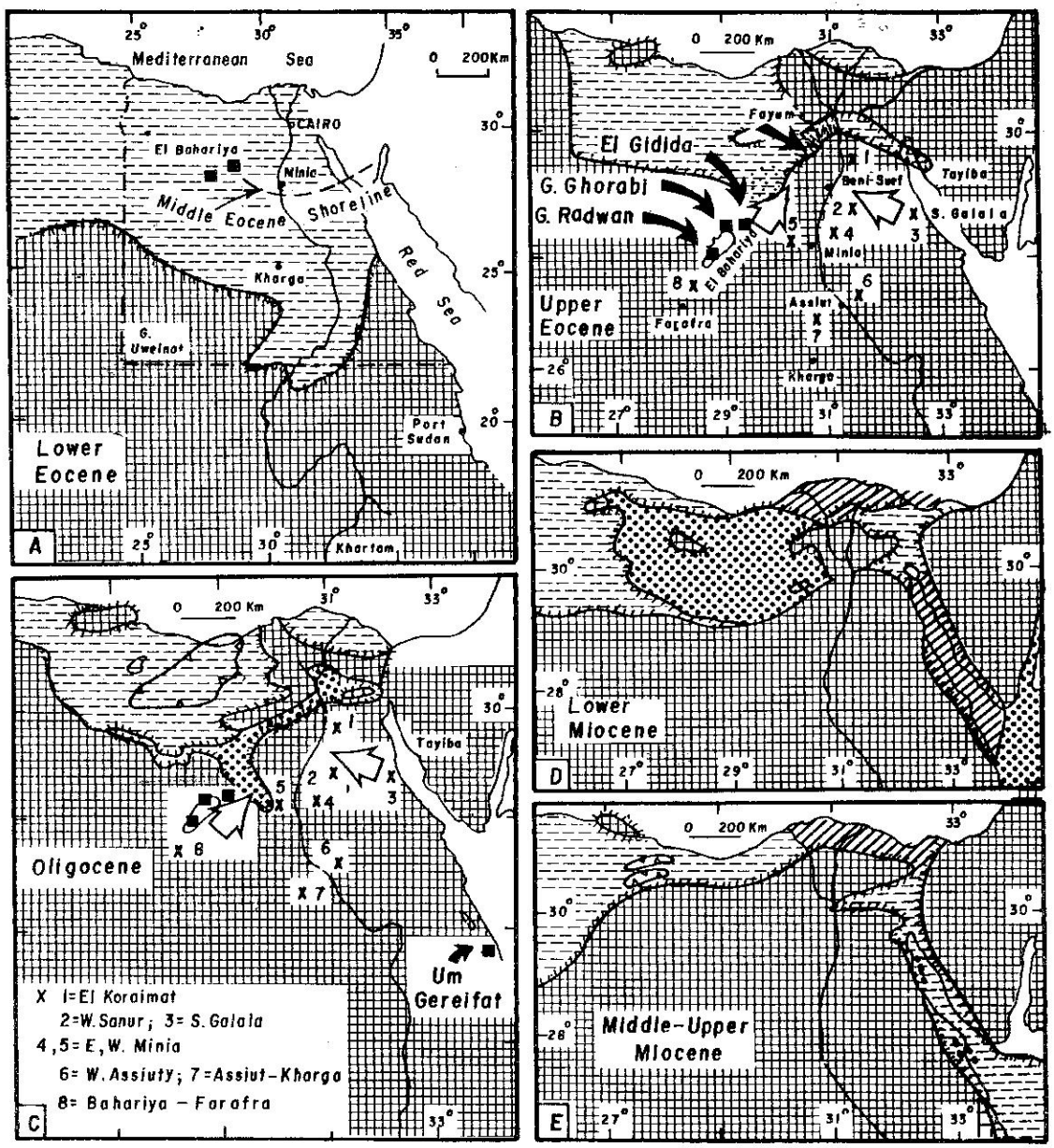
Two groups of Cenozoic stratabound and stratiform ore deposits can be distinguished, based on their paleogeographic position and stratigraphic set-up: a) Paleogene lateritic Fe deposits and karst-related "Egyptian Alabaster" that developed in responce to the Eocene-Oligocene sea retreats and contemporaneous karstification and lateritization of the hinterlands, with karst rejuvinations during younger times, and b) Neogene rift-related deposits coincided with the Red Sea rifting and related coastal facies, uplifts and erosions.

Paleogene lateritic Fe Ore Deposits And Karst-Relate "Egyptian Alabaster"

These types of deposits are either confined within fossil Middle Eocene and pre-Miocene (Oligocene ?) paleoerosion surfaces or form surficial duricrust mantling different exposed stratigraphic units. They occur to the south of the Upper Eocene - Oligocene paleo-shorelines (Figs. 7B,C) and can be classified as follows:

1. Fossil lateritic Fe ore confined within intra-Middle Eocene paleokarst. To this type corresponds El Gidida mine (El Bahariya depression, Western Desert, Fig. 7B and Fig. 8, section 3), where karstified Middle Eocene ferruginous dolostones and mudstones with chert concretions belonging to the Naqb and Qazzun formations rest unconformably upon Cenomanian paleohigh. Intensive karstification of these Middle Eocene rocks gave rise to solution dolines, channels and cavities with varieties of collapse breccias. Reprecipitated Fe sesquioxides with kaolinite, gibbsite, tripoli earth and ferruginated plant remains fill the solution openings or form crustified layers around highly disintegrated and reddened breccia fragments (El Aref and Lotfy, 1989). Ore conglomerates accumulated within the large-scale dolines, indicating local reworking of the ore prior to the deposition of the overlying succession. These ore components correspond to genetic types I and II of El Sharkawi *et al.* (1987). The karstified rocks and related ore are unconformably overlain by a succession of glauconitic sandstones intercalated with ironstone and alunite bands and nodules (genetic type III of El Sharkawi *et al.* 1987). Lenses of ore conglomerates are encountered within the lower part of this glauconitic succession. Northward of El Gidida mine area, the glauconitic sandstones change laterally into shallow marine mudstones and oyster banks of the upper Middle Eocene Hamra Formation (Fig. 8). This formation is truncated by fluvial clastics dominated by rhizoliths which are identical to those of the Oligocene Qatrani Formation of the Fayum area (Fig. 8).

In discussing the space and time of the ore formation of this locality, the original lithofacies associations of the host Middle Eocene carbonates, their paleotopographic and paleogeographic positions as well as their lateral thickness and facies changes should be considered. The Naqb and Qazzun formations are of limited distribution and generally restricted to the northeastern plateau of El Bahariya depression, where they attain together about 60 m thick. High relief prevailed during their deposition. Eastwards towards the Nile Valley, the Naqb Formation changes into or intertongues with the fossiliferous limestones of the Minia Formation which is much more thicker (Fig. 8). Also the Qazzun Formation is correlated with the thicker limestones of the Samalut and Maghagha formations (Fig. 8). This E-W thickness and facies changes can be obviously attributed



1 2 3 4 5 6 7 Fe 8 X 9 10 11

1=Positive areas ; 2=Shelf sediments ; 3=Bathyal sediments ; 4= Fluviomarine sediments ; 5=Deltaic sediments ; 6 = Fluviatile sediments ; 7= Nullipore reefs ; 8= Fe laterific deposits (karst-related in Ghorabi and El Gidida mine areas); 9 = "Egyptian Alabaster" (karst-related calcareous duricrusts and cave fills) with terra-rossa ; 10= Depocenters ; 11 = Possible paleocurrent direction.

Fig.(7) Paleogeography of the Cenozoic series (Fig 7 A after Klitzsch and Wycisk 1987; Figs. 7 B-E after Said (1990b) and distribution of the related stratabound deposits.

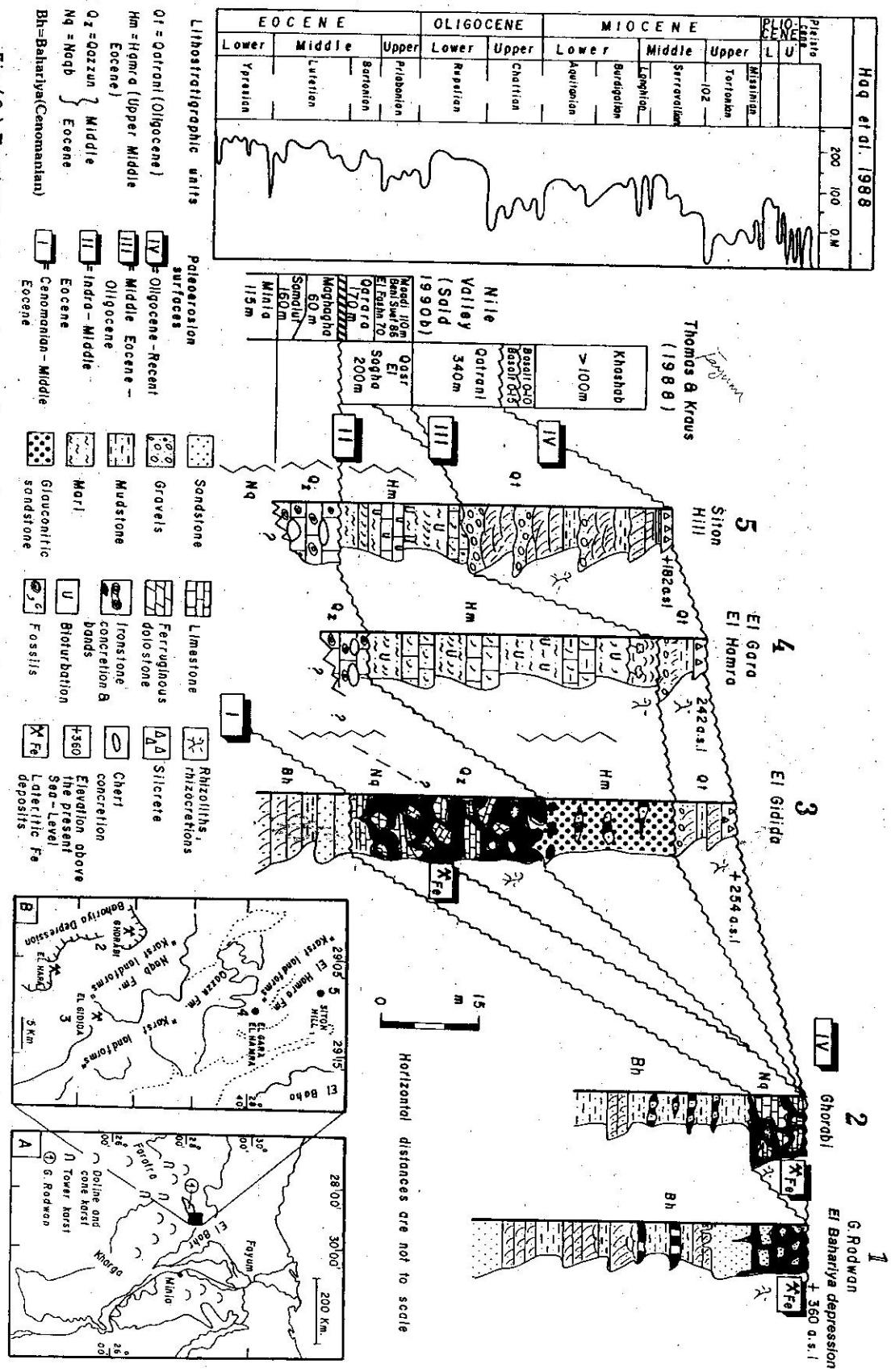


Fig. (8) Tertiary paleoerosion surfaces and related iron ore deposits of El Bahariya region, Western Desert; in comparison with eustatic sea level changes.

to the influence of the Bahariya paleohigh, as a response of the "Syrian arc" tectonic movement, during the deposition of the Middle Eocene carbonates. On the other hand, the paleokarst surface seperating the Qazzun and Hamra formations in El Gidida mine area is correlated with the equivalent unconformity seperating the Maghagha Formation of the Nile Valley from the overlying Qarara Formation (= Hamra Formation), (Fig. 8). This stratigraphic break and the related paleokarstification indicate a phase of emergence and sea level fall during the Middle Eocene which coincides well with a global sea level change (Fig. 8). Facies and thickness changes appear to be extended during the upper Middle Eocene time, when oyster banks and coastal glauconitic sandstones of the Hamra Formation (up to 43 m thick) were deposited to the north of El Bahariya depression and the coeval thicker carbonates of the Qarara Formation (up to 170 m thick) were deposited in the Nile Valley.

2. Fossil pre-rift (Oligocene ?) alumino-ferruginous latosol cropping out in Um Gereifat area, Red Sea coastal zone (Figs. 7C & 9; El Aref, 1993a). The latosol profile comprises three transitional horizons including: a basal slightly weathered Precambrian granite; a middle saprolite horizon and an upper Al and Fe- rich laterite horizon. The topmost laterites are truncated by the proto-rift fanglomerates of the Ranga Formation (Late Oligocene-Early Miocene).

The continental Red beds of Wadi Tayiba (Gulf of Suez, Fig. 7) which unconformably overlies Upper Eocene limestones and disconformably underlies Oligo-Miocene basalts and Miocene sediments also argue for the lateritization during the Early Oligocene.

3. Fe-rich lateritic blankets (surficial ferricrite duricrusts) which were generated during the morphologic evolution of El Bahariya depression, Western Desert. The most promising ferricrete type is highlly-ing, forming an indurated and dissected surficial crusts (9-16 m thick) of constant altitude (270-320 m a.m.s.l.) capping the bevelled summits of isolated conehills, inselbergs and flat-topped mesas. Such topographically high crusts denote remnants of an old continuous erosion surface or peneplain (Oligocene-Miocene ?, El Aref *et al.* 1991) and delineate the level of paleowatertable . They consist of residual Fe oxide and hydroxide mixed with variable proportions of Mn, Al and Si sesquioxides and organic remains. These products form pisoliths and nodules as well as crustified layers around solution and collapse breccias, terrigenous quartz grains, fossil and root moulds. They show downward transitions into brecciated parent rocks (Fig. 8, sections 1 & 2). These lateritic blankets represent the products of *in situ* deep weathering processes (involving karstification) that acted upon exposed Cretaceous clastics in the southern part of El Bahariya depression (e.g. El Heiz area, Gabal Radwan and Sandstone Hill, El Aref et *al.* 1991) and the Middle Eocene Fe-bearing carbonates (Naqb Formation) in the northwestern corner of the depression (e.g. Gabal Ghorabi, El Aref and Lotfy, 1989). They remained exposed to erosion since that time (Fig. 8).

Low-lying thin ferricrete crusts are also detected in El Bahariya depression. They are genetically related to subsequent echplanation and pedimentation processes (post-Miocene - Quaternary, El Aref *et al.* 1991) that acted upon the old erosion surface and related duricrust and were responsible for the excavation of El Bahariya depression through slope and scarp retreats.

4. Karst calcareous deposits (surficial calcareous duricrusts and cave fills, "Egyptian Alabaster"). This deposit type represents the karst-related reprecipitated calcium carbonates and the associated terra-rossa soil which are known in the Egyptian literature as the "Egyptian Alabaster" or travertine. Paleokarstifications of multierosion cycles have had significant effects upon the landscape development of the

Cretaceous and Eocene carbonates cropping out south of the Upper Eocene Oligocene paleo-shorelines (Figs. 7 B & C; 8 A & B). The southern carbonate landscape is formed of successive duricrusted plain surfaces of different altitudes; each one is encrusted by a specific type of surficial duricrust which grades downwards into karstified carbonates. In addition to the aforementioned ferricrete, calcrete duricrusts are commonly distributed . dolocrete and silcrete are also detected above some erosion surfaces. Such duricrusted paleokarst surfaces are widespread in the carbonate plateaus of the Eastern and Western Deserts and along the Gulf of Suez and Southern Galala plateau. They truncate Cretaceous and Paleocene chalks and Lower, Middle and Upper Eocene carbonates (Abu Khadra *et al.* 1987; El Aref *et al.* 1987; Philip *et al.* 1991). Solution dolines and infilled channels and cavities of different shapes, diameters and topographic levels are commonly distributed within and below the paleokarst surfaces. Remnants of the higher surfaces present in the form of accordant summits of mature or degraded duricrusted cone- and tower-karst landforms, facing main scarps or distributing within plained large scale dolines (Fig. 8A). Solution cavities with intra-karstic precipitates have been also exposed to weathering and remnants of infilled caves are widely distributed on Lower peneplains. The geographic distribution of the most representative paleokarst features and related intra-karstic precipitates ("Egyptian Alabaster") and surficial duricrusts (terra- rossa) are shown in Figures 7 B&C.

The high-lying calcrete duricrust of Gabal Homrete Shaibun, east Beni Suef which truncated Upper and Middle Eocene carbonates (Philip *et al.* 1991) can be tentatively correlated with the high-laying ferricrete of El Bahariya depression. The lower paleokarst surfaces of east Beni Suef are attributed to subsequent pre-Nile paleoerosion cycles accompanied with certain drainage basin evolutions (Philip, 1991), which most likely coincided with the general lowering of the Miocene and post-Miocene sealevels. However, further broad correlations of comparable paleokarst surfaces and levels in the whole karst landscape of the Eastern and Western Deserts will be required, taking into consideration their relation with the Tertiary to Recent drainage system evolutions of Egypt and the impact of local or regional tectonic movements. This may assist in better understanding of the karstification history of the carbonates of the Eastern and Western Deserts and the evolution of the associated paleohydrolic cycles.

Neogene Rift-Related Ore Deposits, Red Sea

The Neogene deposition under the Red Sea rifting dynamic resulted in a series of mixed clastic, carbonate and evaprite facies associations exhibiting variable stratigraphic set-up and lateral distributions (e.g. Montenat *et al.* 1988; El Aref, 1993b). They can be classified into four main stratigraphic sequences punctuated by regional unconformity surfaces (Fig. 9). The basal unit (Late Oligocene - Early Miocene Ranga Formation) unconformably onlapps pre-rift Precambrian, Cretaceous and Eocene rocks and Oligocene latosol. It consists of continental clastics and paleosols interbedded with basalt flows. The succeding unit, the Middle Miocene Um Mahara Formation, overlies irregular relief of pre-existing pre- and syn-rift units and includes mixed clastics and carbonates of tidal flat, lagoonal, reefal, beach, subtidal-intertidal and supratidal environments. The upper carbonates of the Um Mahara Formation are truncated by a paleokarst surface related to a main phase of rift faulting, postdating the development of this unit. Following this paleokarst event is the deposition of a relatively thick succession of subaqueous and sabkha evaporites (the Middle to Late Miocene Abu Dabbab Formation in the Red Sea and the Gemsa Formation in the Gulf of Suez). South of Quseir, supratidal - intertidal dolostones of the Upper Miocene Pliocene? Um Gheig Formation terminates the Neogene sequence. It either overlies

the Abu Dabbab Evaporite or in some places (e.g. Um Gheig and Essel mine areas) rests on the Um Mahara Formation. The Um Gheig Formation was followed by rift faulting producing juxtaposition of different fault blocks of variable topographic releif and eastward progradation of the shoreline. During the Plio-Pleistocene time span, paleokarstification took place on the elevated rift blocks, while along the contiguous shoreline and lowlands, continental and coastal sedimentations led to the accumulation of the fluviomarine Mersa Alam, Shagara and Samadi formations of Philobbos *et al.* (1989), followed by Quaternary coastal deposits and wadi alluvium.

Numerous small-scale, economic and non-economic, stratabound and stratiform Ba and Sr sulphates, Pb, Zn and Fe sulphides, S and Mn oxide and hydroxide are intimately related to some of the above mentioned syn-rift depositional environments and paleokarst surfaces (Fig.,9). The main characteristics of these ore types and the geological situations in which they occur are demonstrated in Figure 9. They may be listed as follows:

1. Stratiform to stratabound galena in the beach sandstones of the basal part of the Um Mahara Formation, cropping out in Essel and Zug El Bohar mine areas (El Aref and Amstutz, 1983).

2. Stratiform (layered) pisolitic Mn ore, up to 80 cm thick, conformable with the upper lagoonal algal limestones of the Um Mahara Formation and cropping out in Gabal Abu Shaar El Qibli (El Aref and Abdel Moteleb, 1992).

3. Stratiform celestite of rhythmic crystallization texture confined to restricted supratidal evaporitic limestones which constitute the upper part of the Um Mahara Formation at Wadi Essel (El Aref, 1993b).

4. Stratabound intra-karstic celestite (celestite stalagmites and stalactites) related to the paleokarstification of type 3 and its host rocks during the post- Um Mahara - pre-Abu Dabbab paleokarst event (El Aref, 1 993b).

5. Stratiform barite layers or laminae confined to restricted sabkha facies of the Abu Dabbab Evaporite (Abdel Wahab and Ahmed, 1987).

6. Stratiform and stratabound biogenic sulphr deposits associated with bitumenous materials and/or surface oil seepages and confined to sabkha stromatolitic carbonates and evaporites of the Abu Dabbab Formation (e.g. Ranga and Um Rheiga occurrences, El Aref, 1984; Abdel Wahab and Ahmed, 1987) or the coeval Gemsa Formation (e.g. Ras Gemsa and Gabal El Zeit occurrences, Shukri and Nakhla, 1955; Wali *et al.* 1989; Youssef, 1989). In the Ranga occurrence, the sulphur with anhydrite, calcite and bitumen form stratiform rhythmic bands and laminae, while in the other occurrences. The sulphur occurs as disseminated granules and fracture and cavity fillings and is commonly associated with secondary selenitic gypsum and crustified calcite.

7. Stratabound karstic barite confined to karst features scattering within the Abu Dabbab Evaporite sequence (e.g. Gabal Abu Ghorban, El Aref and Ahmed, 1986).

8. Stratabound Pb, Zn and Fe sulphides with varieties of Pb and Zn sulphates, carbonates, chlorides, phosphates, molibdates and silicates as well as Fe oxide and hydroxide, silica, Ca, Mg and Fe carbonates and kaolinite (e.g. Um gheig mine area). This mineral assemblage is hosted in a karst fill mass developed along a major NW-SE rift fault as a response of the Plio-Pleistocene (post- Um Gheig) paleokarst event (El Aref and Amstutz, 1983; El Aref *et al.* 1986; El Aref, 1993 a&b).

The sulphide varieties (i.e., galena, "shalenblenda", framboidal pyrite and marcasite) with organic remains, calcareous mud and sparry calcite constitute the ma-

trix and cement of the infilling collapse breccias along the lower reducing imbibtion zone of the host karst profile. The "oxide" varieties represent the product of the upper neutral to acidic permanent criculation zone of the karst profile. The karstified host rocks and the associated ore are mantled by calcrete duricrust which is dominated by calcified rhizoliths. Among this deposit type are the karst-hosted sulphides of Wizr, Gabal El Rusas, Anz, and Ranga occurrences.

Surficial manganese and barite deposits, long extracted from Halaib- Elba region, are described in detail by El Shazly and Saleeb Roufaiel (1959) and Basta and Saleeb (1971). They exhibit features and textures of supergene processes that acted upon Precambrian granites and Miocene rocks and most likely related to the Plio-Pleistocene weathering event.

CONCLUSIONS

The occurrence and genesis of the concerned stratiform and stratabound ore deposits are linked to the geological evolution of the Phanerozoic Era. They are clearly related to sedimentary processes which evolved in certain space and time and responded to the paleogeographic evolutions of the paleo-shorelines and related marginal facies and erosional areas as well as paleoclimates. Thus, their distribution pattern (Fig. 1) is not simple, but rather the result of cumulative geological parameters. Non of these deposits shows any genetic relation with volcanic activities or evidences favouring migration of elements from deep seated sources.

The studied ore deposits range in age form Early Paleozoic to Plio- Pleistocene (Table 1). Paleozoic ore deposits include: a) stratiform malachite confined to Cambrian shore-face paleoenvironment, and b) Stratabound karst-hosted Mn ore related to intra-Carboniferous epeirogenic movement and paleokarstification of uplifted Carboniferous Mn-bearing carbonates.

Mesozoic deposits comprise: a) Jurassic-Cretaceous stratiform ironstones of marginal (paralic) paleoenvironments and laterites associated with the general southward transgressive trend of the epicontinental Tethyan seas and the coeval lateritization and continental sedimentations on the hinterlands. The development of these ironstones matches well with the formation of the Jurassic-Cretaceous ironstones of the middle northern latitudes and the eastern margin of Gondwana (Van Houten, 1985) which were also restricted to the marginal facies of the epicontinental Tethyan sea. On the other hand, the Egyptian Mesozoic laterites coincide with the global Mesozoic laterites reviewed by Bardossy (1981) and Valeton (1983), and b) Late Cretaceous phosphorites of shallow marine facies of the epicontinental Tethyan sea. They constitute portion of the extensive Middle East - North Africa phosphogenic province of Late Cretaceous - Paleogene age (Glenn and Arthur, 1990).

Cenozoic ore deposits encompasses: a) Paleogene Fe laterites (karstic in part) and karst calcareous deposits ("Egyptian Alabaster") confined to paleoerosion surfaces which were generated during the northward Eocene-Oligocene sea retreats and paleokarstification and lateritization on the hinterlands, with karst rejuvinations during younger times, and b) Neogene rift-related Pb, Zn, Mn, S, Ba and Sr stratiform and stratabound deposits coincided with the Red Sea syn-rift coastal facies, uplifts and erosions. It is unlikely to attribute these Neogene ore deposits with their host lithologies and facies to rift-related sea-floor spreading and hot brines. Worthmenting, the northern part of the Red Sea rift is in its embryonic stage and sea-floor spreading with hot brines have only recently started and found only in the present Red Sea trough. Also, neither deep water sediments nor indications of hot brine pools are recorded in the syn-rift Neogene succession of Egypt.

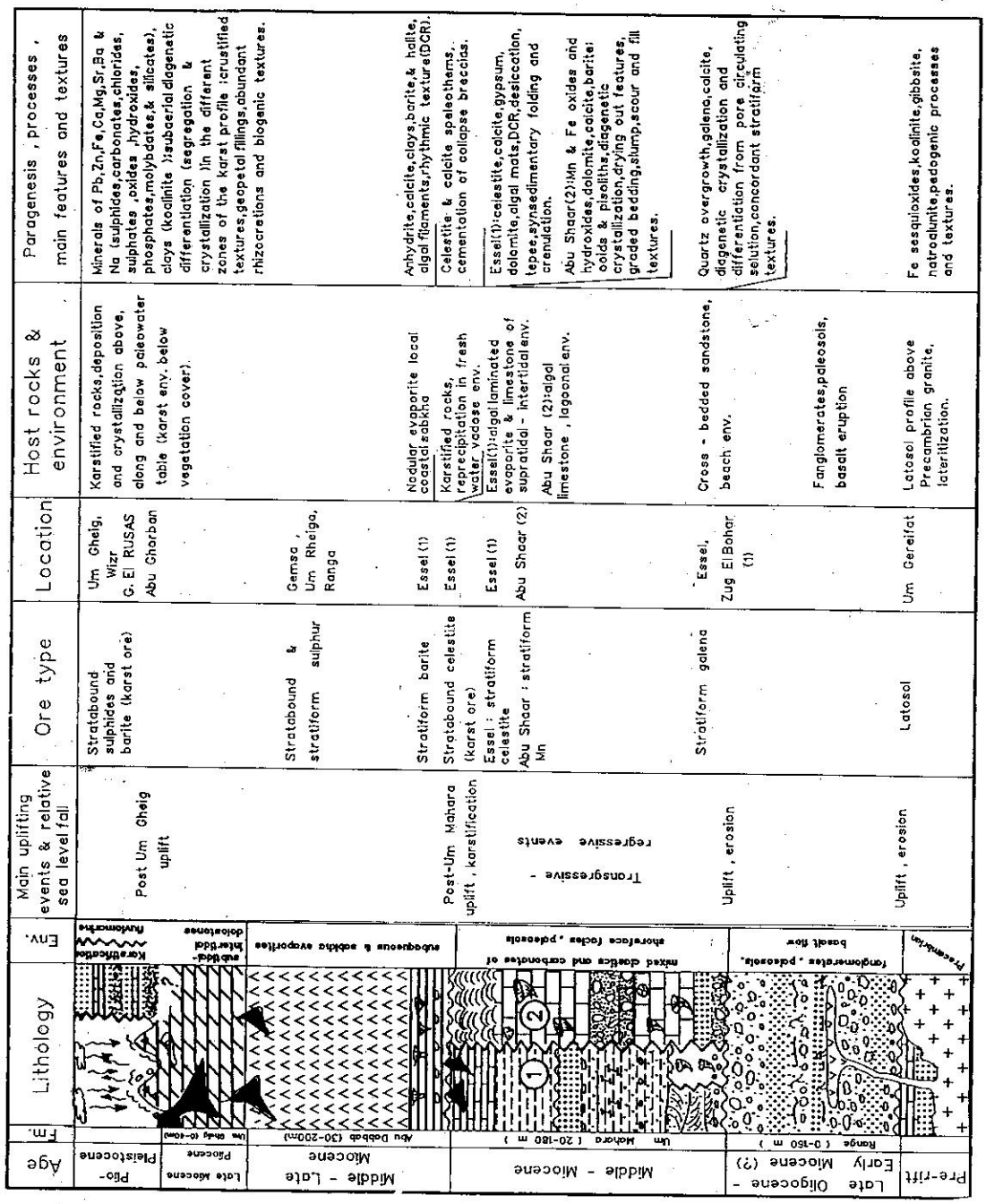


Fig.(9)Syn-rift sedimentation,uplifts,erosion and related ore deposits in the Red Sea coastal zone between latitudes 25° and 28°N.

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